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Experimental study on the properties of steel fibre reinforced concrete

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ABSTRACT

The research work deals with an experimental investigation of the properties of steel fibre reinforced concrete (SFRC). It studied thirteen samples of SFRC mixes of M30 concrete of varying dosage of 3D and 5D steel fibres; ranging from 25kg/m^3 to 45 kg/m^3. The SFRC specimens were tested for various properties: specific density, workability, compressive strength and toughness index. The effect of specific gravity, steel fibre dosage, and water to cement ratio on the properties of SFRC also explored individually and in combination. Experimental results showed that workability of the fresh SFRC decreases slightly on increasing the dosage of steel fibre. However, the slump value decreases more rapidly for the same SFRC after 25 minutes of its preparation. The experimental and graphical analysis indicated that use of steel fibre improves the compressive strength of the SFRC mix at both 7-days and 28-days of curing considerably beyond the designed strength of the concrete i.e. 30MPa. The toughness indices, determined as I5 and I10, also

increased with increasing dosage of steel fibre and increasing specific gravity at the water to cement ratio of 0.42. The results also showed that 5D steel fibre provided a better anchoring within the concrete matrix which ultimately improves its compressive strength and flexural properties in terms of toughness index.

Keywords: steel fibre, concrete mix, workability, slump, compressive strength, toughness index

1. INTRODUCTION

Concrete is one of the most consumed man-made materials in the field of construction. It is a composite of cement, water, aggregates and also different types of admixtures in a particular ratio (Tiwari and Sharma 2016). The fresh concrete has a property of plasticity before casting but it gets hard like a rock due to chemical reactions between cement and water with the advancement of time (Alberti, Enfedaque et al. 2017). The durability of the concrete structures is used to be based on ordinary Portland cement, round steel bars of mild steel. With time these materials are replaced by Pozzolana cement and TMT bars respectively (Yoo and Banthia 2017). Moreover, concrete is no more considered as a simple compound of material consisting of cement, aggregate, water rather assumed to be an engineered material which can exhibit properties such as high fluidity, self-compactable, high strength, high durability, better serviceability and long service life. However, the two properties still has limited its use are; its brittleness and weak tension (Shah and Ribakov 2011; Pająk and Ponikiewski 2013; Marcos-Meson, Fischer et al. 2019).

The last two decades have witnessed an extensive utilization of fibrous substances: steel fibre, polypropylene fibre, plastic fibre, glass fibre, agricultural waste fibre, waste tyre rubber fibre in preparing different types of concrete such as lightweight concrete, foam concrete, high-performance concrete, temperature resistant concrete, corrosion-resistant concrete, etc (Khan, Cao et al. 2018; Marcos-Meson, Michel et al. 2018; Naraganti, Pannem et al. 2019; Wang, Dai et al. 2019; Chen, Zhong et al. 2020).

However, the he applications of steel fibre reinforced concrete (SFRC) in mine and tunnel lining; thin shell dome and dam construction; rock stabilization, repairing of surface and fibre protective coatings have been growing steadily (Zhao, Chen et al. 2019; Liew and Akbar 2020). SFRC is a combination of conventional concrete and steel fibres which can be mixed and placed by types of equipment as used for conventional concrete. SFRC has also found its application in high temperature, up to 815°C, refractory concrete (Chidighikaobi 2019). The fibre volume percentage and fibre effectiveness have its bearing on the behavior of SFRC. However, the volume fraction, orientation, shape, geometry etc of steel fibre have significant effect on the SFRC properties (Yazıcı and Arel 2013; Eik, Puttonen et al. 2016; Soufeiani, Raman et al. 2016; Tavakoli, Jalali et al. 2019). Thus, it is imperative to investigate the best SFRC design and its mechanical properties with varying steel fibre for its effective use.

The broad objective of the present study is to investigate the effect of steel fibre (SF) composition on the fresh and hard properties of concrete of grade M30. However, the specific objectives of the present study were to design M30 concrete mixes with different proportion of steel fibre and determination of their density; to determine the effect of different proportion of steel fibre on the workability, compressive strength and toughness index (I5 and I10).

2. MATERIALS AND METHOD

Materials used

Cement: This study used Ordinary Portland cement (OPC) of 53 grades (Ambuja brand) because of its faster rate of development of strength. Table 1 presents the properties of the cement used.

Table 1 Properties of Ordinary Portland cement

Properties	Value
Fineness	340 gm /kg
Specific gravity	3.15 g/cc
Initial setting time	140 min
Final setting time	250 min
Specific gravity of cement	3.15

The cement used has initial and final setting time of 140 min and 250 min respectively.

Water: The correct amount of water in concrete mix cause proper cement hydration and maximize the strength. In present research, the water used in all mixes was local tap water. The required water-cement ratio used for this study varies in the range of 0.42 - 0.45.

Aggregate: The aggregate is classified as fine aggregate and coarse aggregate. Fine aggregate is material passing through an IS sieve that is less than 4.75mm gauge beyond which they are known as coarse aggregate. According to IS 383:1970, the fine aggregates classification, the study used the crushed sand of Zone-II (Harog Crusher in Ramban, Jammu & Kashmir, India). The coarse aggregate of a maximum of 20 mm is suitable for concrete work. Besides their size, shape and surface have significant impact on fresh and hardened properties of concrete. The properties of fine and coarse aggregate are summarized in Table 2.

Table 2 Properties of Fine and Coarse Aggregate

Properties	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.59	2.64 (10 mm) 2.69 (20 mm)
Water absorption	0.55%	0.6%
Fineness Modulus	1.78	3.45
Water Absorption	1.79	0.47 (10 mm) 0.25 (20 mm)
Free surface moisture	Nil	Nil

Coarse aggregate forms the main matrix of the concrete, whereas fine aggregate forms the filler matrix between the coarse aggregate. The most critical function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also facilitates the cement paste to hold the coarse aggregate particle in suspension.

Steel fibre: The characteristics and performance of Steel Fibre Reinforced Concrete, (SFRC) changes with varying concrete binder formulation as well as the fibre material type, fibre geometry, fibre distribution, fibre orientation and fibre concentration. The research work utilized DRAMIX 3D and 5D in different fractions. The properties of Steel Fibre are presented in Table 3.

Table 3: Properties of Steel Fibres Used

Properties	Value
Length (L)	60 mm
Diameter (d)	0.90 mm
Aspect Ratio(L/d)	65
Specific gravity	7.85
Tensile Strength	1.160 N/m^2 (3D) 2.300 N/m^2 (5D)
Tolerances	± 7.5% avg.

Admixture: The study used super plasticizer DCP (Supaflo PC460A) of specific gravity of 1.08 having a brand name of Hyperplast S-40 used to reduce water requirement and to improve the concrete workability.

Method

Mix Design Consideration

The study dealt with the investigation of the performance characteristics of SFRC. The various samples of SFRCs prepared were same proportions of cement content, fine and coarse aggregate, water, admixture etc. The concrete mix in each case (M30 grade) was prepared using the procedure for concrete mix design calculation as per IS 10262-2009. The standard mix proportion composition is presented in Table 4.

Casting and Curing

According to the goal of this study and related tests, the following specimens were cast from each mix:

- For evaluation of compression test: 150 mm cubes
- For evaluation of flexural test: one 150 × 150 × 600 mm beam
- For evaluation of impact resistance test: one 150 × 600 mm cylinder

Table 4 Mix Proportions Compositions for Sample Concrete

Mixed Design Sample	W/C ratio	Corrected Mix Proportion (kg/m^3)							
		Cement	Water	20mm CA	10mm CA	crusher sand	Admixture		Steel fibre
Requirement as per IS code	0.45	340	186	35%	25%	40%	0.6 % to 2.2 % max		---
1	0.43	340	147	680	414	860	1.40%	4.9	40 (3D)
2	0.43	340	147	675	415	864	1.40%	4.9	40 (3D)
3	0.43	340	147	685	412	856	1.40%	4.9	40 (3D)
4	0.43	340	147	680	414	860	1.40%	4.9	40 (3D)
5	0.43	340	147	685	400	865	1.40%	4.9	40 (3D)
6	0.42	340	143	678	417	868	1.40%	4.9	45 (3D)
7	0.42	340	143	680	416	861	1.40%	4.9	45 (3D)
8	0.42	340	143	678	417	868	1.40%	4.9	45 (3D)
9	0.42	340	143	672	415	873	1.40%	4.9	45 (3D)
10	0.42	340	143	668	421	870	1.40%	4.9	45 (3D)
11	0.41	340	140	700	498	774	1.20%	4.6	40 (5D)
12	0.44	340	151	670	426	865	1.40%	4.9	35 (5D)
13	0.42	340	143	699	499	775	1.20%	4.6	25 (5D)

For each test, one specimen was made as the control one. After preparing the moulds concrete was placed in two layers vibrated with tapping the concrete with rod for proper consolidation and concrete compaction. The specimens were cured in fog room with 26+2℃ temperature. The specimens were removed from and cured in temperature controlled water tank for 28 days.

Material Testing

The various tests were conducted on material used to prepare the concrete mix and on the concrete mixes containing various proportion of steel fibre in accordance with the American Standard for Testing of Materials (ASTM) and Indian standards (IS). The following tests were performed

- Sieve Analysis: Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) – 1963.
- Water Absorption: This test helps to determine the water absorption of coarse aggregates as per IS: 2386 (Part III) – 1963. For this test a sample not less than 2000g was used.
- Initial and final setting time: The initial and final setting time as per IS: 4031 (Part 5) – 1988. Vicat's apparatus conforming to IS: 5513 – 1976 is used to determine the initial and final setting times of the concrete.
- Workability of Concrete: Slump cone test was performed to determine the workability of the fresh concrete properties following the IS: 1199 – 1959 code. The test utilized a shape called droop cone whose top distance across is 10 cm, base breadth is 20 cm and height is 30 cm.
- Compressive Strength: Aimil make compression testing machine of capacity 1000KN was employed to investigate the compressive strength of concrete samples using procedure outlined in IS code 516:1959.
- Flexural toughness Test: Flexural toughness is defined as a measure of the energy absorption capacity or it is the ability to withstand crack opening. It is performance of areas under the load-deflection curve or area under stress-strain achieved by testing a simply supported beam under third-point loading specified in Test Method ASTM C 78. The toughness tests are carried out in accordance to ASTM C1018. The specimen crack mouth opening displacement (CMOD) is measured using a clip gauge mounted across the crack faces. The test is performed up to a CMOD of not less than 4 mm. The test method evaluates the flexural performance of fibre-reinforced concrete using parameters derived from the load-CMOD curve, such as limit of

proportionality (LOP) or flexural strength and the residual flexural strength. The test method provides the determination of a number of ratios called toughness indices. These indices are determined by dividing the area under the load-deflection curve obtained by third point loading flexural test, the area up to the deflection at which first crack deemed to have occurred. The entire process is explained in Figure 3.

Figure 1 Fresh Concrete Slump

Figure 2 Compressive2strength of Concrete

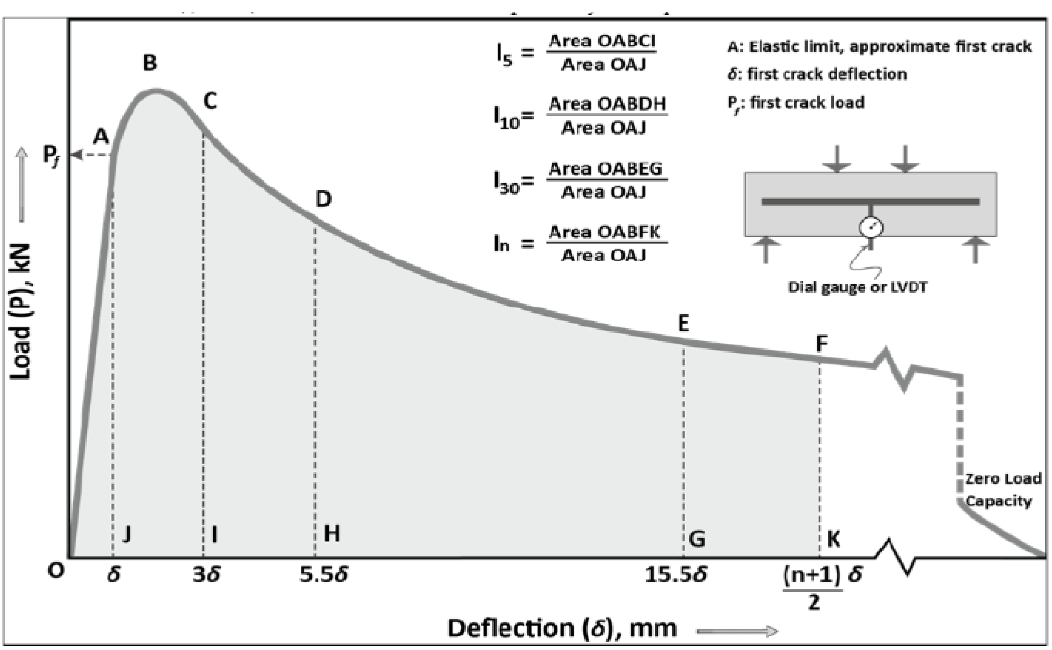

Figure 3 Determination of toughness indices according to ASTM C1018

3. RESULTS AND DISCUSSION

Specific Gravity

Figure 4 shows the average specific gravity for samples of 40 (3D) and 45 (3D). Wherein the values 40 and 50 represent the amount of SF in kg/m^3 of the sample, while 3D and 5D represents geometry of the SF.

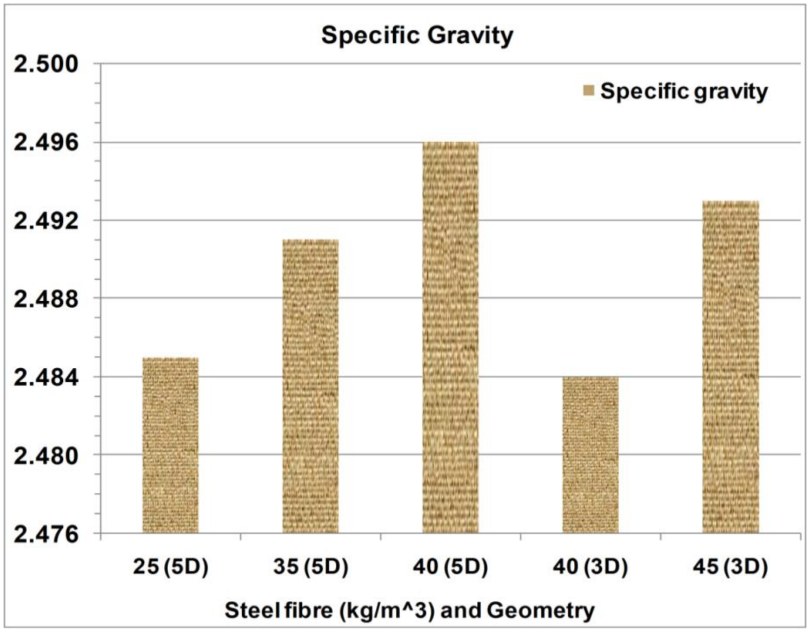

Figure 4 Specific gravity of various SFRC samples

The specific gravity values are observed to be highest and lowest for 40 (5D) and 25 (5D) respectively. More interestingly, the specific gravity of 40 kg SFRC is much higher for the sample containing 5D SF as compared to 3D steel fibre.

Steel fibre reinforced concrete and workability

The workability of designed concrete mix were obtained using slump test. The results of the test are presented in Figure 5.

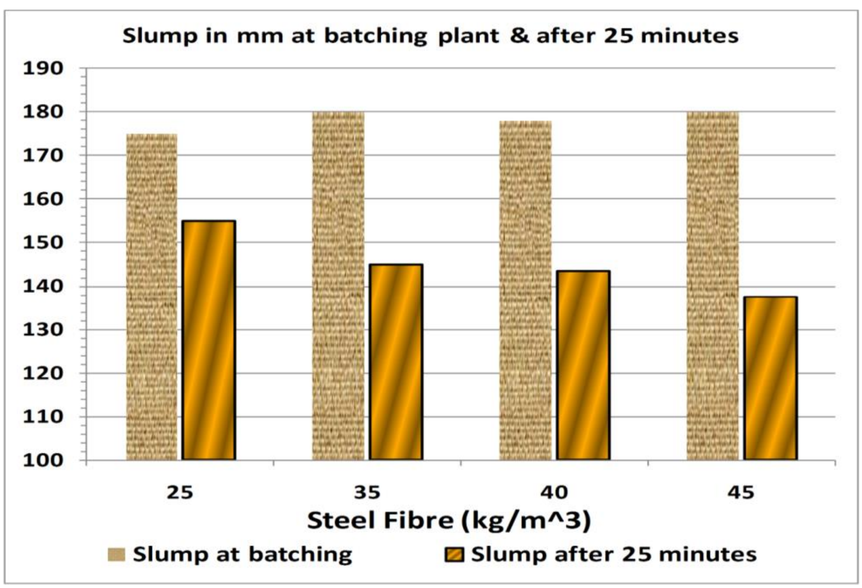

Figure 5 Slump of design concrete mix at fresh and after 25 minutes

Figure 5 represents slump of fresh concrete and after 25 minutes after its preparation for various SFRC samples with varied amount of steel fibre (SF). Slump test conducted on fresh concrete (at t=0) indicates that there is a little variation (increase) in workability with increasing amount of SF. The initial slump of SFRC in all sample was observed between 150 mm to 180 mm, This clearly indicates that initial slump (at t=0) of SFRC doesn't vary quantitatively with increase in fibre dosages. The observation further reveal that slump of SFRC samples are higher than prescribed range of the control plain concrete mix as mentioned in IS code.

In contrast, the slump values at pouring site (at t=25 min) of preparation of concrete steadily decreases with increasing amount of SF. The final slump value measured (at t=25 min) for different sample indicates that with the increase of fibre dosages ,the SFRC

becomes much stiffer causing problem in pumping as more pressure must be applied for smooth exit of SFRC at pumping point. Lower value of slump obtained may also cause difficulty in vibration. However, these values are within the range of 100-150 mm as prescribed by the IS code.

Steel fibre reinforced concrete and compressive strength

Figure 6 illustrates the comparison of compressive strength of SFRC samples after 7-days and 28 days after curing for varied amount of steel fiber dosages (25kg, 35kg, 40kg & 45kg).

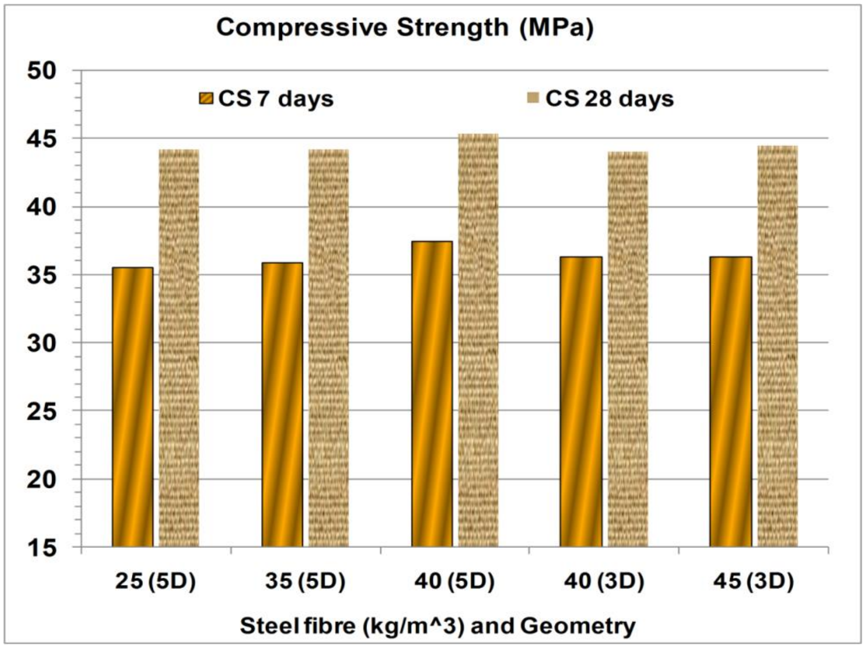

Figure 6 Compressive strength of SFRC samples after 7-days and 28-days

The figure indicates that all the sample attained a compressive strength above 30 MPa (i.e. the designed compressive strength for M30 grade concrete mix) as early as 7-days. It further increases considerably when determined after 28-days of curing of the concrete cube. The highest and lowest compressive strength observed for samples reinforced with 40 (5D) and 25 (5D) SF, respectively after 7-days of curing. Similarly after 28-days of curing, the highest compressive strength was found for the sample that used 40 (5D) SF while lowest compressive strength was observed for the sample reinforced with 40 (3D) SF.

When steel fibre dosages increases (keeping cement content same), there is no significant increase of 7-days and 28-days compressive strength. Moreover, the effect of increasing steel fibre on ultimate compressive strength (28 days) is also found to be insignificant. On addition of 1.4%, 1.6%, 1.8% steel fiber per cumec of concrete, strength does not increased more. All these observations conclude that there is not much role of steel fibre in attaining the compressive strength of SFRC.

Steel fibre reinforced concrete and toughness index

Concrete due to its brittle behaviour has little ability to resist tensile stresses and strains. Discontinuous fibres are added to improve energy absorption capacity and to provide improved resistance to cracking. Thus flexural toughness is an important parameter in assessing the influence of fibres on the post-peak behaviour of fibre reinforced concrete. A number of methods have been developed to obtain the flexural toughness and performance of fibre reinforced concrete. In this study, load-deflection curves (Load vs Displacement) method was used. A typical load-deflection curve obtained for steel fibre-reinforced concrete beams of aspect ratio 65 as per the guidelines of ASTM C1018S presented in Figure 7.

The two toughness index (i.e. I_5 and I_{10}) are determined for comparison of various SFRC samples. I_5 is obtained by dividing the area up to a deflection of 3.0 times the first-crack deflection by the area up to first crack. I_{10} is obtained by dividing the area up to a deflection of 5.5 times the first-crack deflection by the area up to first crack.

Figure 8 shows a big change in toughness index to steel fibers. At 1% , 1.4%, 1.6%, 1.8%, mixing of steel fibers, toughness of steel fiber concrete was increases continually whereas the toughness is not dependent on cement content if the mixing of steel fiber in increasing order that is 1% , 1.4%, 1.6%, 1.8%, then the toughness index increases by 8% to 18% . If the cement content increasing 3% to 4% there was no effect on toughness index. The figure also shows that the Toughness index (I_{10}) of Beam of size

(300x150x150) for different type of steel fiber (i.e. 3D and 5D) is varying considerably. It is evident from the SFRC sample having 40 kg/m^3 of steel fibre of 3D and 5D type. The both form of toughness Indices are larger for the sample having 5D steel fibre as compared to 3D steel fibre. It is possibly because of the difference in the properties of both the 3D and 5 D steel fiber. i.e. tensile strength of 3D is 1.160 N/msq & Tensile strength of 5D is 2.300 N/msq. Besides that the geometry of 5D steel provides better anchoring of the concrete matrix as compared to 3D steel fibre as shown in the Figure 8. In general, the highest and lowest values of toughness indices were observed for SFRC samples designed with 40(5D) and 25 (5D) steel fibre.

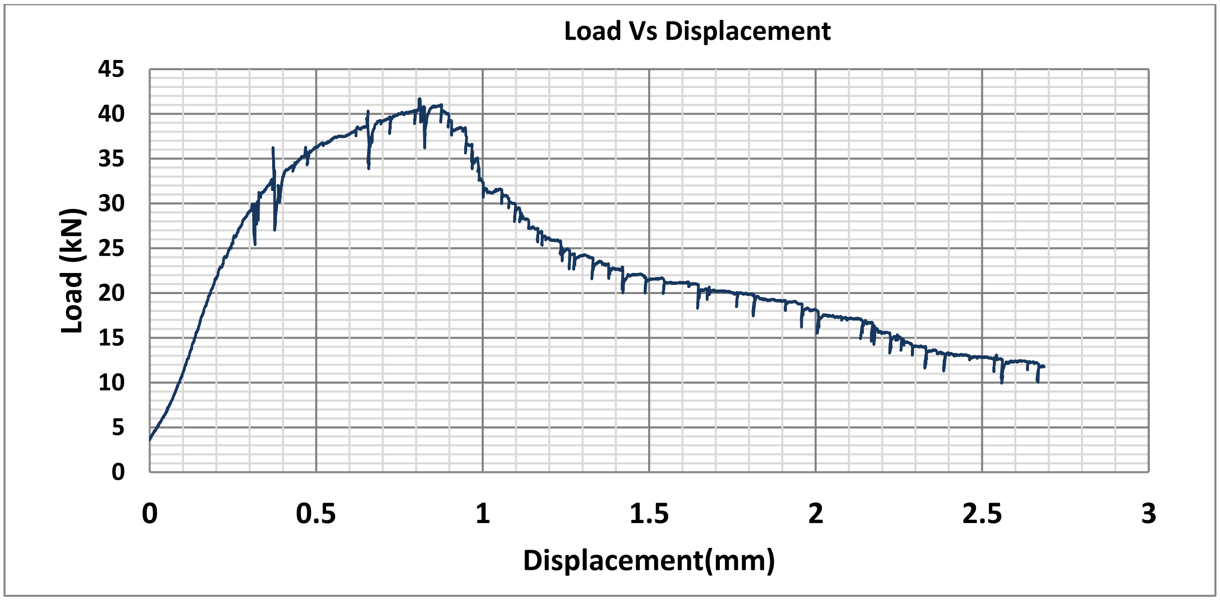

Figure 7 Load vs displacement curve after 28 days for aspect ratio 65

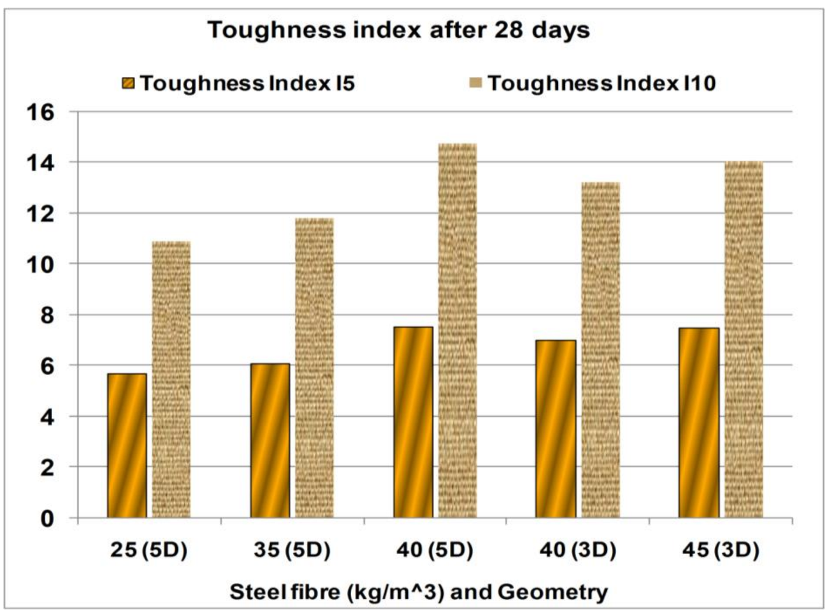

Figure 8 Toughness index I_5 and I_{10} for steel fibre with aspect ratio 65

Figure 9 and Figure 10 present the combined effect of specific gravity, fibre percentage and water cement ration on the slump values at t=0 and t= 25 min respectively.

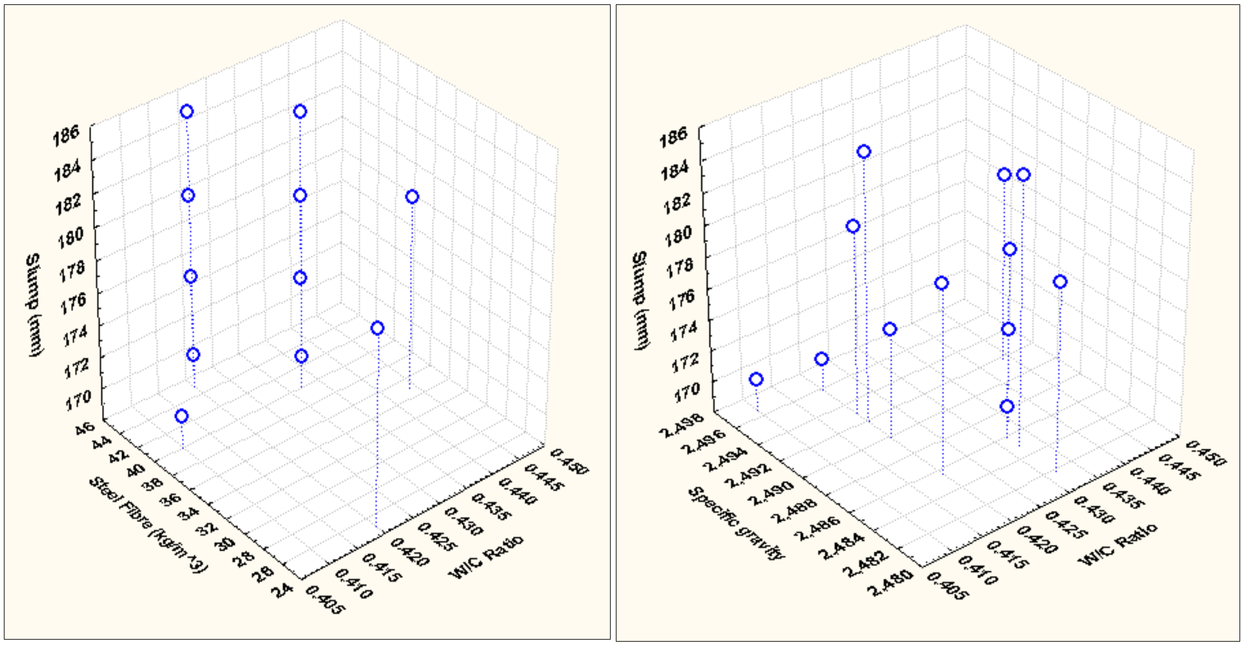

Figure 9 Effect of steel fibre, W/C ratio and sp. Gravity on slump (t=0)

Figure 9 suggests that for obtaining a high slump values SF dosage of 45 kg/m^3 along with w/c ratio of 0.42 is desirable. Similarly, a specific gravity of 4.92 and w/c ratio of 0.42 is favorable conditions for obtaining high slump value of fresh SFRC.

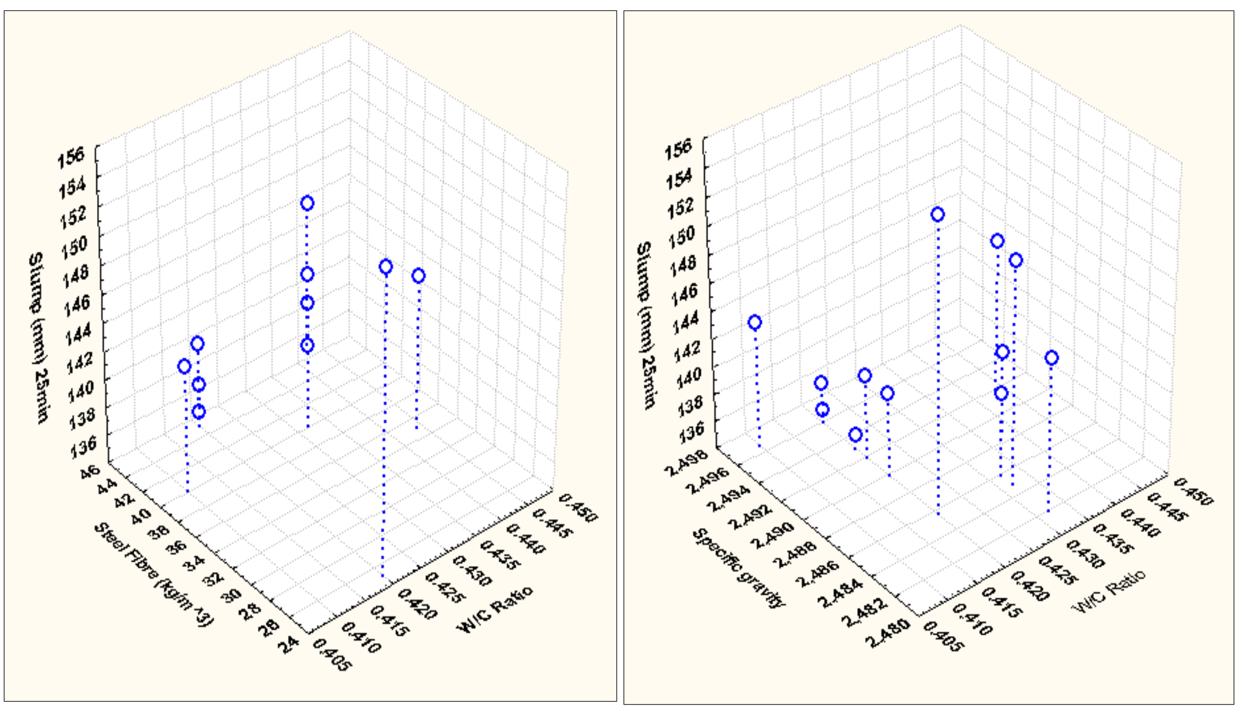

Figure 10 Effect of steel fibre, W/C ratio and sp. Gravity on slump (t=25)

The combined effect of SF and W/C ratio and combined effect of specific gravity and W/C ratio on the values slump (t= 25) are displayed in Figure 10. The figure demonstrates a different trend. A combination W/C ratio of 0.42 and SF of 25 kg/m^3 favoured the slump value more. Similarly, specific gravity of 2.498 and W/C ration of 0.415 facilitate SFRC to obtain the high slump values.

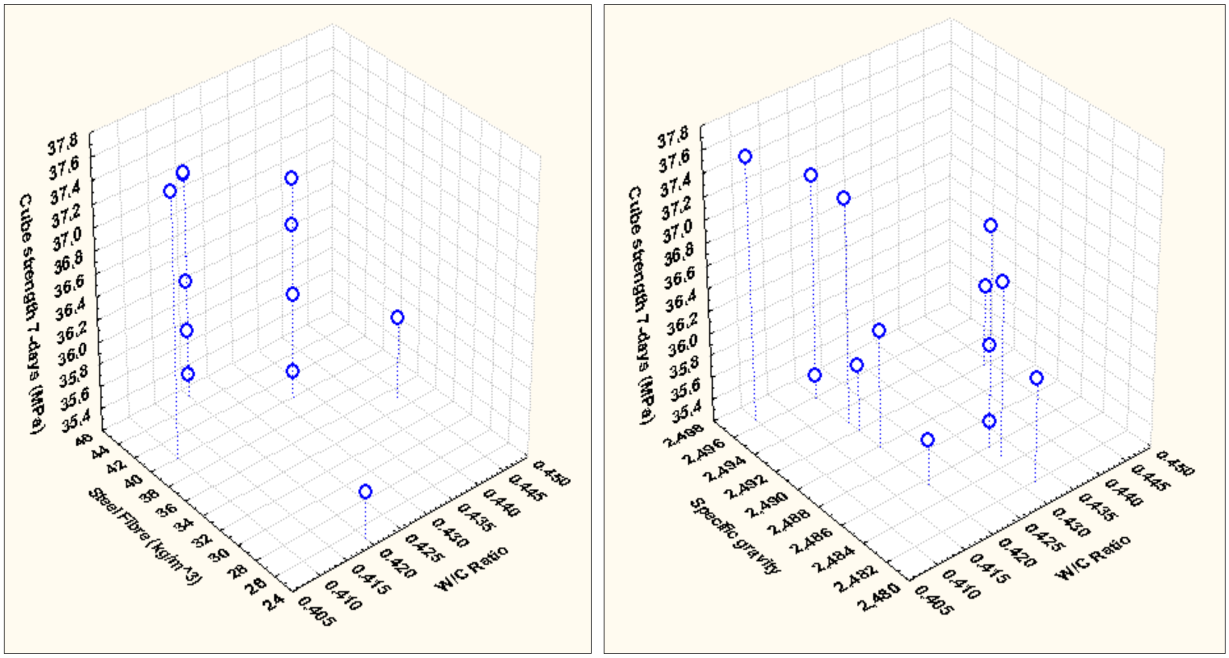

Figure 11 Effect of steel fibre, W/C ratio and sp. Gravity on compressive strength (7-days)

The synergistic effect of SF dose and W/C ratio, and the combined effect of specific gravity and W/C ration on the compressive strength after 7-days of curing is present in Figure 11. It reveals that a high steel fibre along with relatively low value of W/C ratio is desirable for obtaining high compressive strength. A value of W/C ratio as 0.415 and SF dose of 45 kg/m^3 gave the highest compressive strength at 7-days. On other hand, specific gravity of 2.498 and W/C ratio as 0.415 is resulted best value of compressive strength.

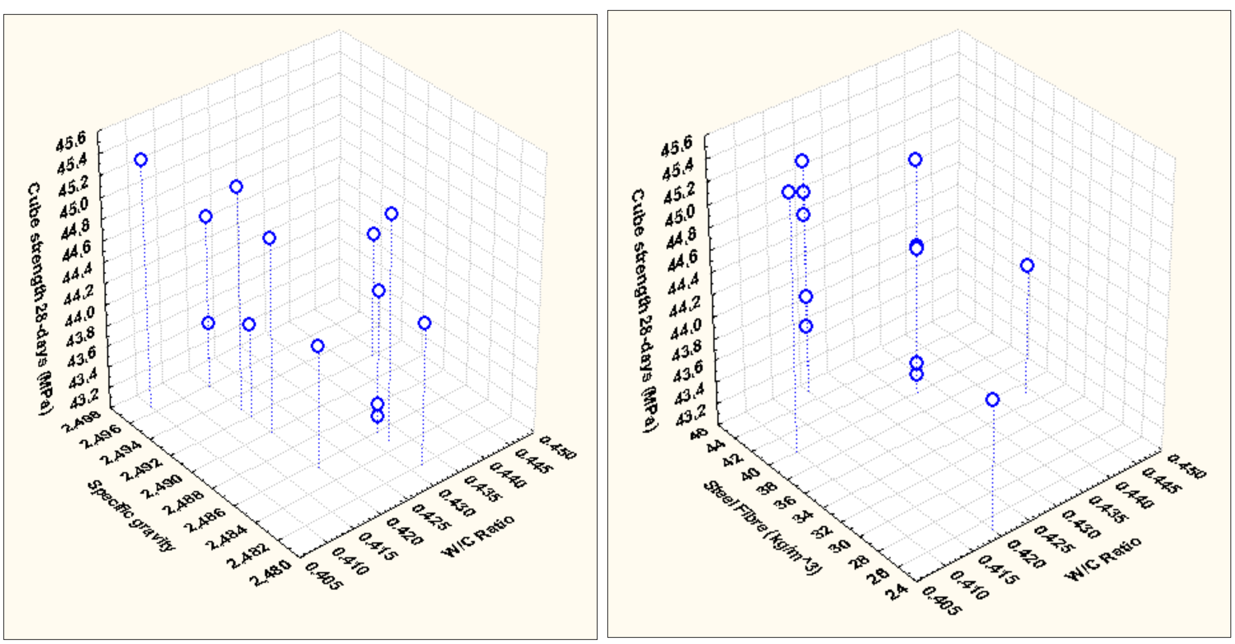

Figure 12 Effect of steel fibre, W/C ratio and Sp. Gravity on compressive strength (28-days)

Figure 12 shows that synergistic effect of SF dose and W/C ratio, and the cumulative effect of specific gravity and W/C ratio on the compressive strength at 28-days of curing. Although it showed similar trend of observation in both cases as we observed for compressive strength at 7-days of curing, but the effect is not distinct or pronounced here.

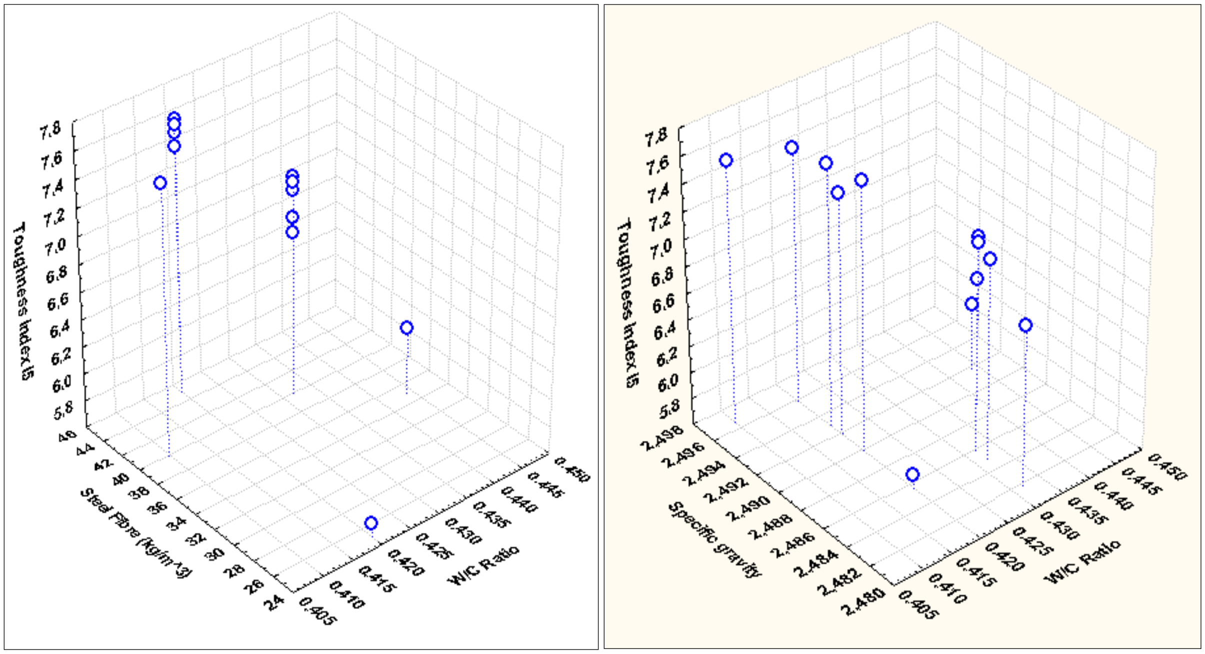

Figure 13 Effect of steel fibre, W/C ratio and sp. Gravity on Toughness index I_5

The cumulative effect of steel fibre dosage, specific gravity and water to cement ratio on the toughness indices are presented in Figure 13 and Figure 14.

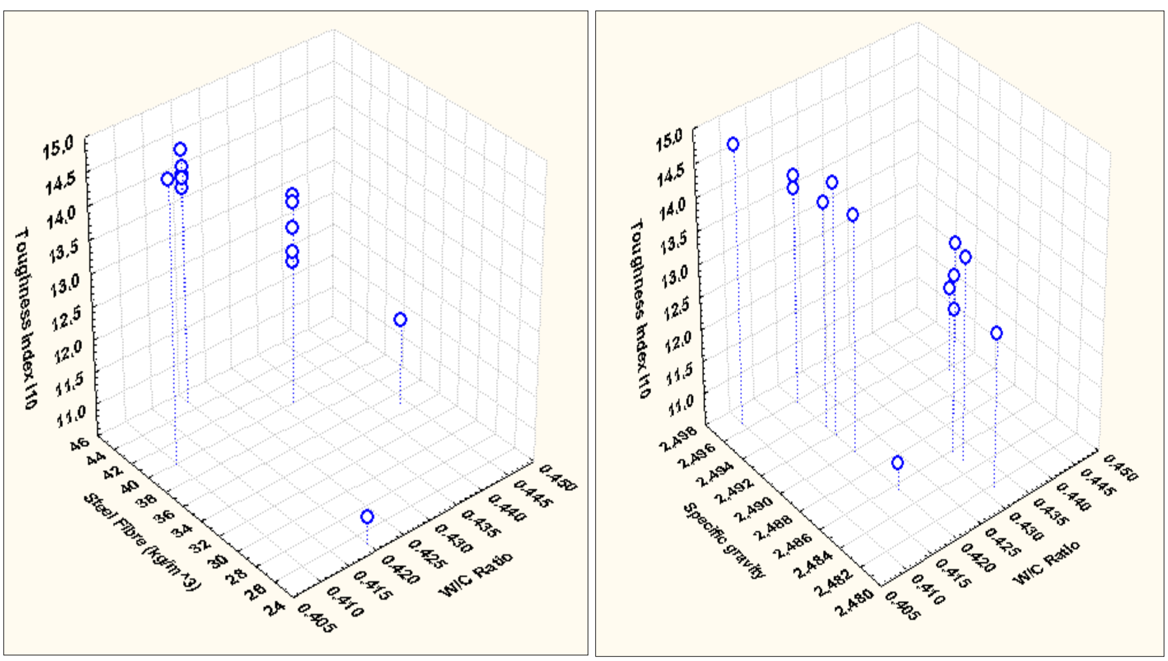

Figure 14 Effect of steel fibre, W/C ratio and sp. Gravity on Toughness index I_{10}

These show a similar repsonse of both I5 and I10 to the changing values of the SF dosage , specific gravity of the concrete and W/C ratio. From these figure it is evident that a higher value (45 kg/m^3) of SF along with a W/C ratio of 0.42 is the most favorable for obtaining the larger toughness. Similarly, a higher specific gravity (2.498) along with W/C ratio of 0.41 is best for designing a SRFC mix with highest toughness index.

4. CONCLUSION

The study is a way forward in making the SFRC more acceptable. It demonstrates a successful design of M30 grade concrete by using 3D and 5D steel fibre. The findings of the study reiterate that SFRC can be used as a supplement in inhibiting cracking, where a thinner-than-normal slab is desired or lining of tunnels, underground mines etc. Some of the specific conclusions are as follows:

- The specific gravity values are observed to be highest and lowest for 40 (5D) and 25 (5D) respectively. More interestingly, the specific gravity of 40 kg SFRC is much higher for the sample containing 5D steel fibre as compared to 3D steel fibre.
- Slump test conducted on fresh concrete (at t=0) indicates that there is a little variation (increase) in workability with an increasing amount of SF. Slump values at t=25 min of preparation of concrete steadily decreases with an increasing amount of SF, though within the prescribed range of 100-150 mm.
- All the SFRC sample mixes attained the required design compressive strength within 7-days which further increase after curing of 28-days. The effect of increasing steel fibre on ultimate compressive strength (28 days) is positive although not that much significant.
- On increasing the steel fibre dosage, there is an increase in toughness index by 8% to 18 %. However, toughness Indices was larger for the sample having 5D steel fibre as compared to 3D steel fibre.
- The higher values of compressive strength and toughness indices were observed for a higher dosage of steel fibre, high specific weight and lower W/C ratio. It is further observed that a dose of 45kg/m^3 of steel fibre and a specific gravity of 2.498 at a water-cement ratio of 0.42 resulted in the highest compressive strength and toughness index.
- SFRC mix with steel fibre 40(5D) at a water-cement ratio of 0.42 yielded the best results among all studied SFRC sample mixes.

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Conflicts of Interest: The authors declare no conflict of interest.

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